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Microstructure and mechanical properties of Ag and Ge multi-micro alloyed Al-(3.2) Cu-(2) Li-(0.6) Mg alloys

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Microstructure and mechanical properties of Ag and Ge multi-micro alloyed Al-(3.2) Cu-(2) Li-(0.6) Mg alloys

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Abstract. This work represent an attempt to investigate the possible improvement to replace (Cu) by (Li) in (Al-Cu) alloys used in aerospace industries. It is well established that (Al-Li) alloys are attractive for military and aerospace application because their properties are superior to those of congenital (Al) alloys. (Li) reduced the weight of the plane; hence, more speed can be attained. Several other improvements are also intruded. Alloys were prepared during this work by casting .they include (Al-Li-Cu-Mg-Zr), (Al-Li-Cu-Mg-Zr-Ag), and (Al-Li-Cu-Mg-Zr-Ag-Ge) alloys. Result showed that addition 0.35%Ag to Al-Li-Cu-Mg-Zr alloy improve strength from (42MPa) to (127MPa) when aging at 175°C.and improve hardness from (156.64 Hv) to (173.74Hv) At the same temperature. But the deterioration when addition 0.2 Ge to Al-Li-Cu-Mg-Zr alloy weakness strength from (127MPa) to (26MPa) at the same time improved hardness from (156.64Hv) to (171.76Hv) at the same temperature. Optical microscopy (OM),X-ray diffraction (XRD) were done to study the structure and the surface features and chemical composition of the alloys. Many phases shown which have an influence on the mechanical and chemical properties, such as (Al_3Li), (Al_3Zr), (Al_2MgLi), omega ( ) precipitates, (Ag_2CuLi), (Ge_4Zr_5).Pin-on-disc testing technique was commonly used for investigating sliding wear. B significant increase in wear resistance of the alloy. The weight loss was only 60% of the other alloys.

Key Words: (Al-Li) alloys, wear test, tensile test.

1.   Introduction

The aluminum-lithium alloy features unique properties such as low density, high elasticity, tensile strength, corrosion resistance, good weighting and high hardness compared with traditional aluminum alloys, so they are suitable for space use. [1, 2]. Space industries always require lightweight materials, high strength, fatigue, corrosion, and thermal stability. Aluminum alloys, for example Al-Cu-Mg and Al-Zn-Mg, have good mechanical properties in addition to their low density. However, the development of this industry has created a constant need for lighter alloys for several reasons:

Increased aircraft operating efficiency reduced fuel consumption and improved flight characteristics, thus increasing interest in aluminum-lithium alloys. [1, 3] .Lithium is the lightest metallic element, with a density of 3.50 µg, the first metal and a third element in the periodic table rank (73Li). It enters into the nuclear bomb with heavy hydrogen for its light weight, and because the bonding energy of the lithium nucleus cannot be combined with heavy hydrogen nuclei , So when

cast with the aluminum with a density of 2.7g.cm-3 will reduce the density of the resulting alloy to less than the density of aluminum.

Lithium is the only metal that, when inserted with aluminum in the alloy increases the modulus of elasticity and reduces density. Each percent of lithium is added to the aluminum. The density decreases about .0.08 g.cm-3 [1, 2, 4]

These alloys have a very high resistance to chemical corrosion compared to other aluminum-lithium alloys, and these alloys have higher thermal stability properties than other aluminum alloys. [**2,3**] . But the main problem with the use of these alloys lies in the difficulties and constraints in the preparation. Lithium is a very effective element and burns rapidly when exposed to air. There are several research projects to solve this problem, such as: The process of partial protection of lithium with aluminum foil to prevent it from being exposed to air, or to add it in an empty atmosphere or under an atmosphere of inert gases such as Alarcon, in order to prevent its oxidation, in addition to the treatment costs associated with such methods and what may be caused by oxides or others In the fused alloy after freezing.

The first experience of using lithium as a casting element with aluminum was more than half a century ago, and it has undergone many stages of development. For this purpose, many researches were carried out in universities and industrial companies. This was not used commercially until 1958, as well as their high sensitivity. [1, 3, 4]

2. Experimental procedure

2.1. Preparation of samples

The chemical composition of Al-Li-Cu-Mg alloys examined in this investigation is shown in Table (1). Was melted and cast in vacuums induction furnace under Ar atmosphere .the ingot was then homogenized, and hot rolled to a 4mm thick for heat treatment. The samples obtained were solution treated at 560°C for 1 h followed by ice water quenching, and then aged at 175°C for different time periods.

Table (1): Chemical composition (weight %) of alloy.

No	Alloy	Li	Cu	Mg	Zr	Ag	Ge	Al
1	A	2	3.2	0.6	0.11			Bal.
2	B	2	3.2	0.6	0.11	0.35		Bal.
3	C	2	3.2	0.6	0.11	0.35	0.2	Bal.

2.2. XRD

The X-Ray Diffraction (XRD) measurements were also carried out in an X´Pert PRO MPD diffract meter using Cu K radiation at 40Kv and 35mA setting in the 2 range from 20° to 120°.

2.3. Microstructure examination

Some alloys were prepared for microscopic imaging using OLYMPUS (BH - 2) microscopy.The smoothing stages were carried out on the KNUTH-ROTOR. The polishing process was done on the mechanical polishing machine (CREICHRT.DP-20). As for the solution of the demonstration, use Keller's Reagent solution with the following structure:(1 cm3 HF, 1.5 cm3 Hcl, 2.5 cm3 HNO3, 95 cm3 H2O) with a show time ranging from 10 to 15 sec.

2.4. Hardness Tests

The micro hardness account for all alloys used in the search after aging. For each test an average of three readings was recorded. In this work, micro Vickers hardness testing machine type **(a Digital Micro hardness tested HV1000)** (HV) The micro hardness was used to evaluate product, with load 1000g with socking time 10 sec. Micro hardness values were obtained by using the equation:

$$H = 1.854\frac{P}{d^2} \quad \text{………………………..[1]}$$

Hv: Hardness Vickers (kg/mm²).
P: applied load (Kg).
d: the average diameter of the indentation (mm).

2.5. Wear Tests

The alloys are dimension (20*29*5mm), which were weighed by a Sensitive balance of (±0.0001, where it was weighed before and after the wear test. The wear apparatus is a rotational type micro-tester (pin on disc) MT4003version 10 was adopted, .The sliding wear was determined by using pin on disk concept using (300r.p.m) and constant radius (6mm). A martensitic steel disc was used with Ra=0.265µm and Hv=852.The wear test was carried out using load (15N).They were examined after grinding of up to (2500).the duration of the tests was (10, 20, 30, 40, 50, and 60). The test was performed at room temperature (25ºC).

2.6. Tensile Tests

Standard specimens alloys were prepared with dimensions shown in Figure(1) according to ASTM (B557m-15) **[5].** Computer control universal testing machine model (WDW) was used with tensile speed rate (0.1 mm/min) at room temperature. The sample shape after testing is shown in Figure (2).
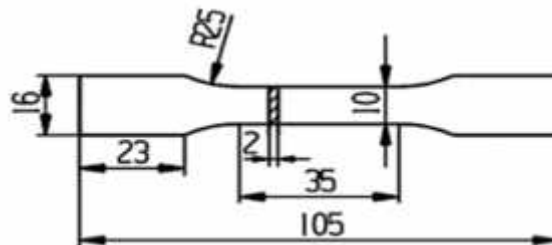

**Figure 1** Standard Tension Test Specimen [5]

Figure 2 Tensile Alloys After testing.

## 3. Results and discussion

3.1. XRD

After heating the alloy D, E, and G at 560° C which were all   phase (super saturation) for about 1hr. and quenched in ice water.

Alloy (A) it found that the aging heat treatment for 12 hr. lead to precipitate the intermetallic compound (Al4Li9) , (Al3Zr) , (Al3Zr5)and (Li6.46Mg) this is accomplished by the decomposition of(Al3Zr) phase. Precipitate fine particles (Al3Zr) will lead to Control of recrystallization shown in figure (3).
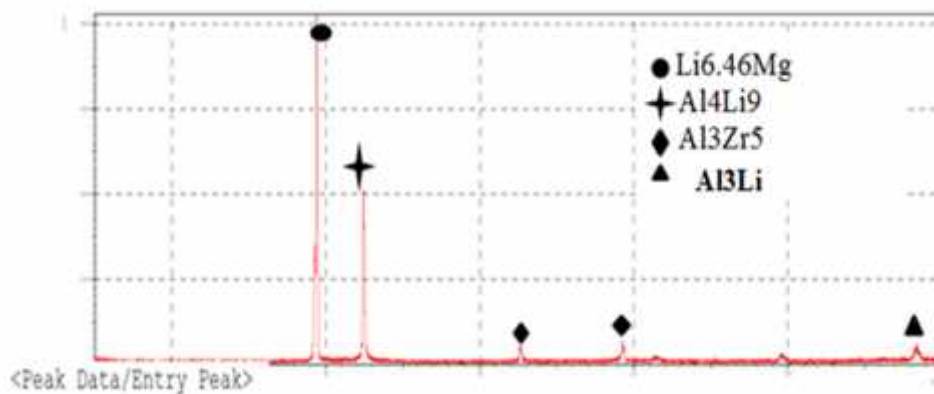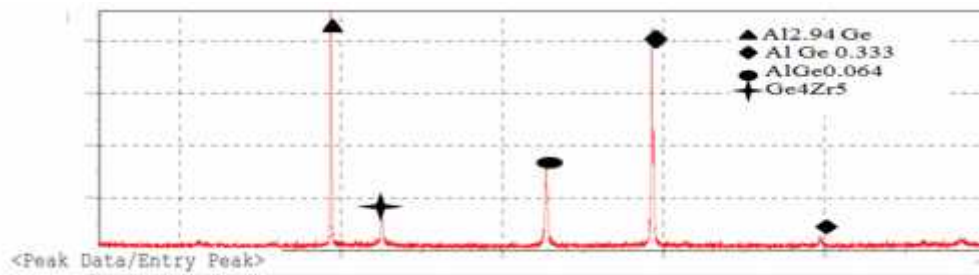

Figure 3 XRD Pattern for Alloy (A) Aged at 175°C for 12hr.

Figure (4) XRD pattern of alloy (B) it found that the aging heat treatment for 12 hr. lead to precipitate the intermetallic compound T1(Al2CuLi), ´(Al3Li), and -type (~AlCu) this is accomplished by the decomposition of ´(Al3Li) phase and T1. The addition of Mg and Ag leads to the formation of omega ( ) precipitates fine particles will lead to increase the strengthening.
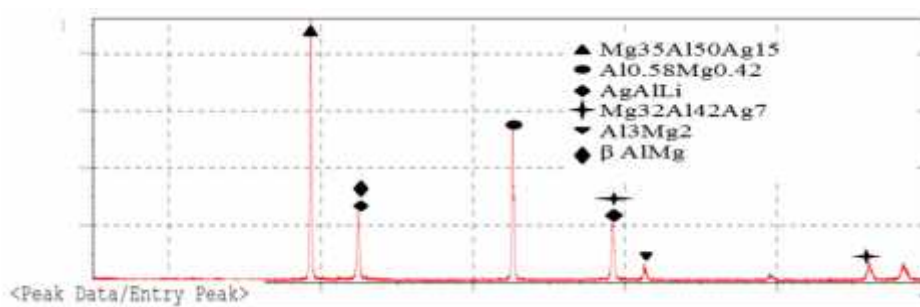
**Figure 4** XRD Pattern for Alloy (B) Aged at 175°C for 12hr

Alloy (C) it found that the aging heat treatment for 8 hr. lead to precipitate the intermetallic compound (Al2.94Ge) , (AlGe0.064) , (Ge$_4$Zr$_5$)and (AlGe0.333) this is accomplished by the decomposition of(Ge4Zr5) phase. Precipitate fine particles (Ge4Zr5) will lead to increases strength shown in Figure (5). The addition of some phases did not appear because of the possibility of the device is old.

Figure 5 XRD Pattern for Alloy (C) Aged at 175°C for 8hr.

3.2. Microstructure

All three alloys in hot rolling and aged condition were examined using optical microscope. It is observed that the A alloy contains the phase (Al_3Zr) which is completely identical with the aluminum matrix which is the source of resistance. Either B alloy was found to be phase ($AgAlLi_2$).The C alloy was found to be Phase deposition (Ge_4Zr_5) it has a hardening base role in this alloy shown as figure (6, A, B, C).
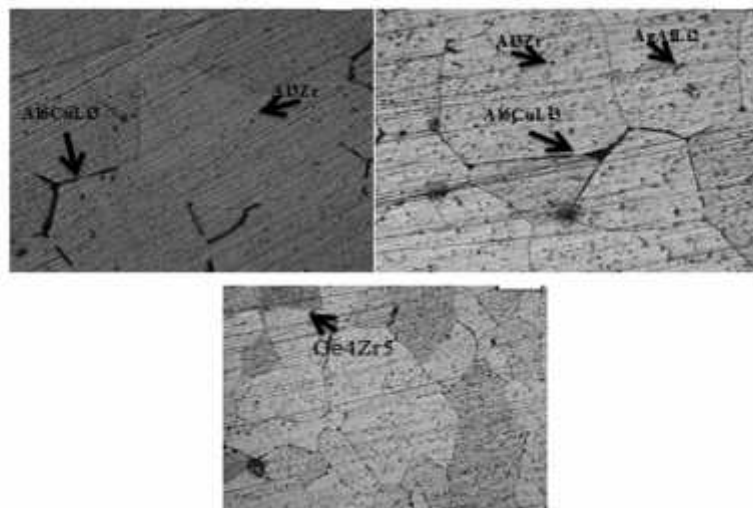
Figure 6 Microstructure of Alloys at 100X magnification;
(A) After Aging 12hr ;(B) After Aging 12hr;(C) After Aging 8hr.

3.3. Hardness

The aging treatment of this alloy was carried out in a typical manner Figure (7) showing the relationship between the hardness and the aging time of alloy A at 175 ° C. Find that the top of her salad at 12 hours reaches 156.6. The superiority of this alloy in hardness is that it contains more than a solid element such as (Mg, Cu, Li, Zr), which are the stages of solidification (T1, S, ´). The difference in the time period to reach the peak of hardness is due to the basic phase (´) in the D-specific growth alloy. For the low mismatch scale, so aging does not occur until the balanced phase (´) and the other phases become apparent. The alloy D is superior to the traditional Al-Li alloy**.**

Al-Li-Cu-Mg-Zr

Hardness (Hv)

156.645   151.4   150.77
124.745   136.98
89.195 104.335

Aging Time (hr)
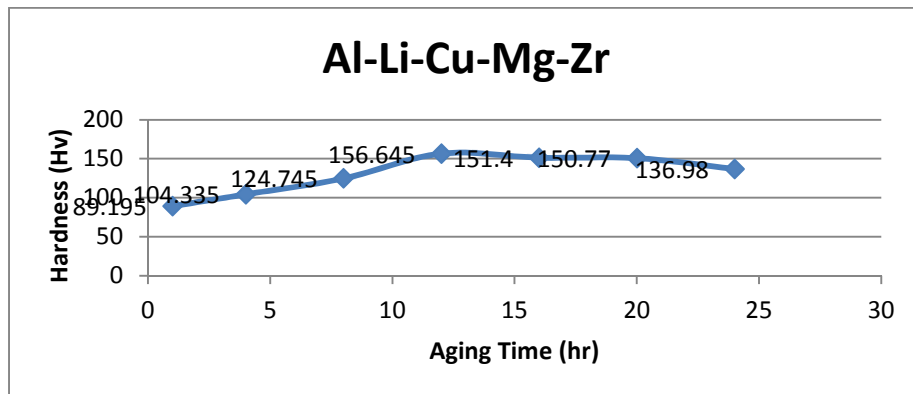
Figure 7 Hardness test of alloy A

The following precipitates are involved in strengthening: T1(Al$_2$CuLi), ´ (Al$_3$Li), and -type (~AlCu). the addition of Mg and Ag leads to the formation of omega ( ) precipitates that are isomorphous and isostructural with the T1phase. In this context, the Ag atoms substitute Cu atomic positions and the Mg atoms substitute Li atomic positions in the T1structure leading to Al(Cu-Ag)(Li-Mg) stoichiometry and atomic arrangements. The -type precipitates are thought to be isomorphous and isostructural with hprecipitates in the Al-Cu system. Shown in Figure (8)

Al-Li-Cu-Mg-Zr-Ag

Hardness (Hv)

164.765   173.745   170.34   168.26
95.75 102.06   160.66
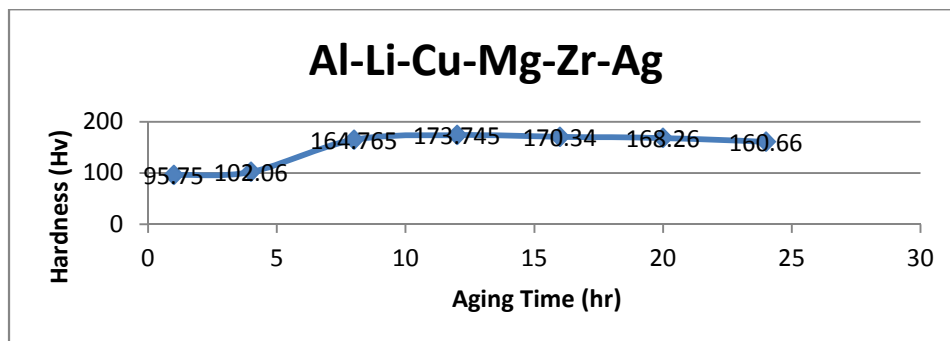
Aging Time (hr)

Figure 8 Hardness test of alloy B

Figure(9) shows the relationship between hardness and aging time, where it was found that the C alloy reaches the top of its hardness at a temperature of 175 degrees 171.76, which is higher than the traditional Al-Li alloy. The germanium element increases the solubility of lithium in aluminum. Phase deposition ´, which is the primary phase of the Al-Li alloy. The germanium component is also mutated from the boundary between the ´ and ground phase moments. The slippage is reduced by increase ductility.
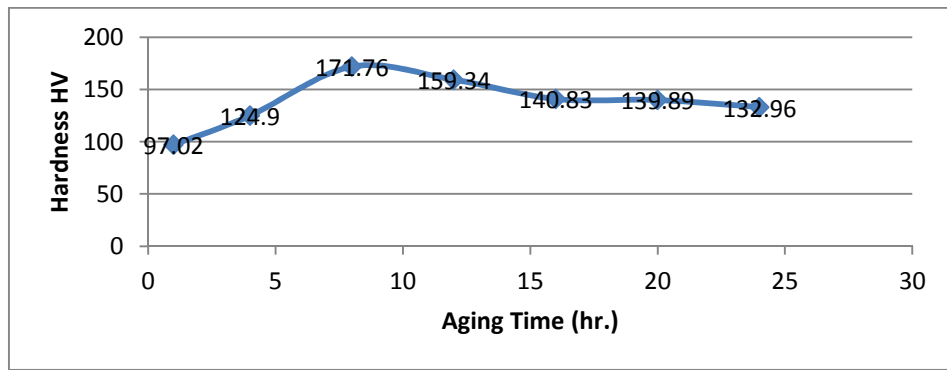
Figure 9 Hardness test of alloy C

3.4. Wear

All alloys were subjected to wear test under load of (15 N) for different times (10, 20, 30, 40, 50, and 60) min at room temperature. From tribological point of view, the reason for a sharp rise in the weight loss within the initial cycles is expected by the process of asperity smoothing in the initial stage of contact, the results are shown in Figures below.
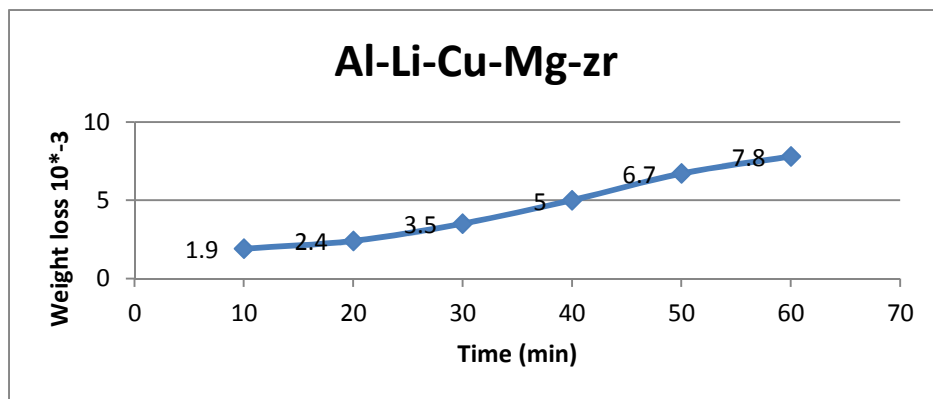
Figure 10 wear test of alloy (A)
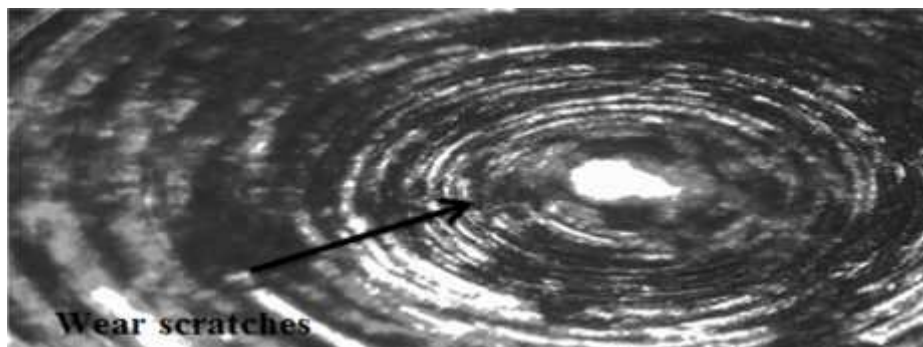
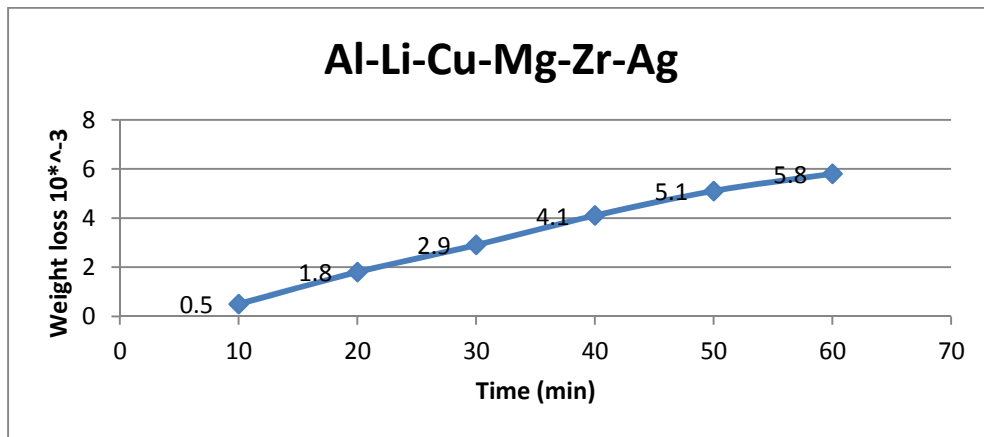**Figure 11** Microscopic image at (15N) load after 1hr. (A) 100x
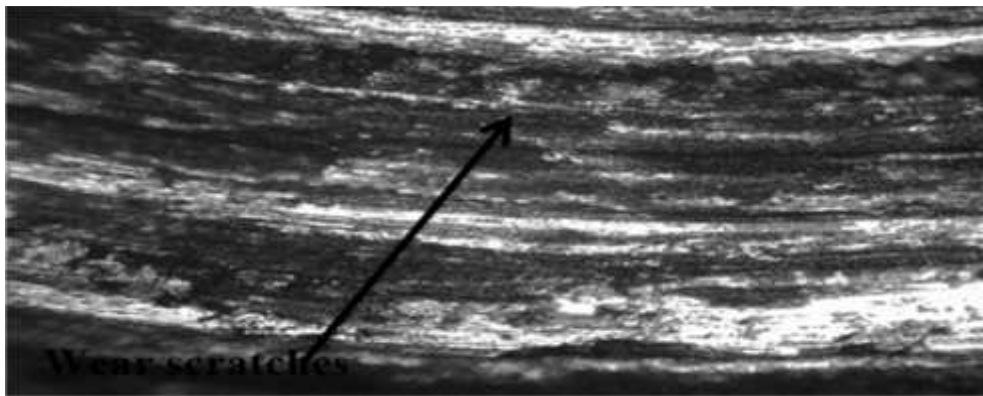
Figure 12 wear test of alloy (B)

Figure 13 Microscopic image at (15N) load after 1hr. (B) 100x
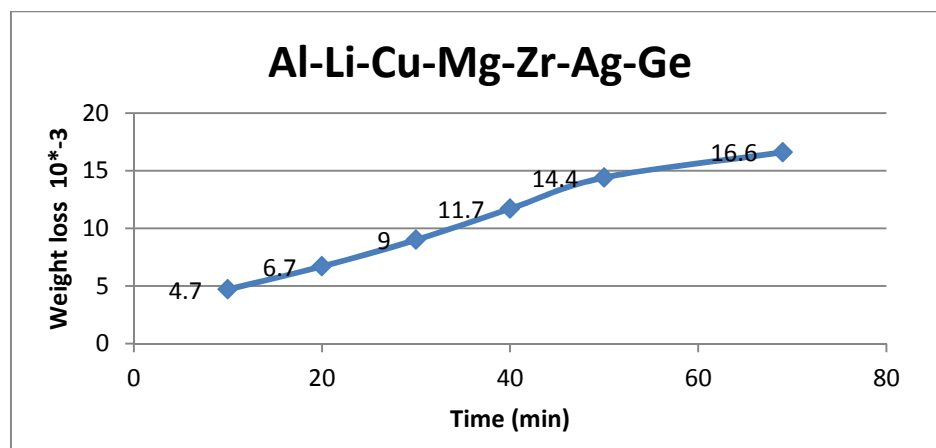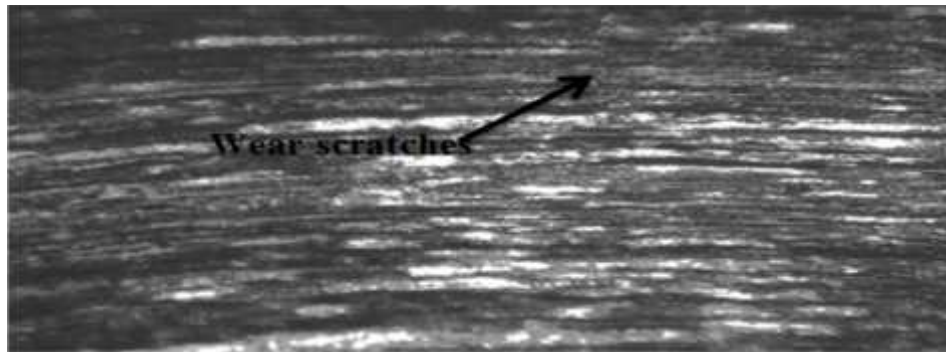

Figure 14 wear test of alloy (C)

Figure 15 Microscopic image at (15N) load after 1hr. (C) 100x

This case, then its respond to stress by brittle fracture rather than plastic deformation, therefore, it is expected that the load is concentrated over a small contact area on the flat sample surface. Hence, the surface asperities fractured in a brittle material in contact positions and the occurrence of fracture loads to increased friction; this provides an additional mechanism for the dissipation of energy at the sliding contact. Therefore, increasing time (sliding distance) the surface asperities of the disc and the sample surface become reduced, leading to a more conformal (favorable) contact.

In other work, the meaning contact pressure become slowly (the contact area increases) therefore the scale of the fracture when it occurs will be small, leading to reduction in the frictional force and weight loss. It is well established that the wear rate depends on the normal load and the hardness or yield strength of the material. Figure (10, 11, 12, 13, 14, 15) shows the wear behavior of the tested samples. The addition Zr to alloys works to reduce loss weight by limit (7.8) because formation of a phase ´(Al_3Zr). The addition Ag to alloys works reduce loss weight about (4.6) because gives more compounds T_1 (Al_2CuLi), ´(Al_2Cu), ´(Al_3Li) ,and   . The addition Ge to alloys works reduces loss weight (16.6) because gives more compound (Ge_4Zr_5).
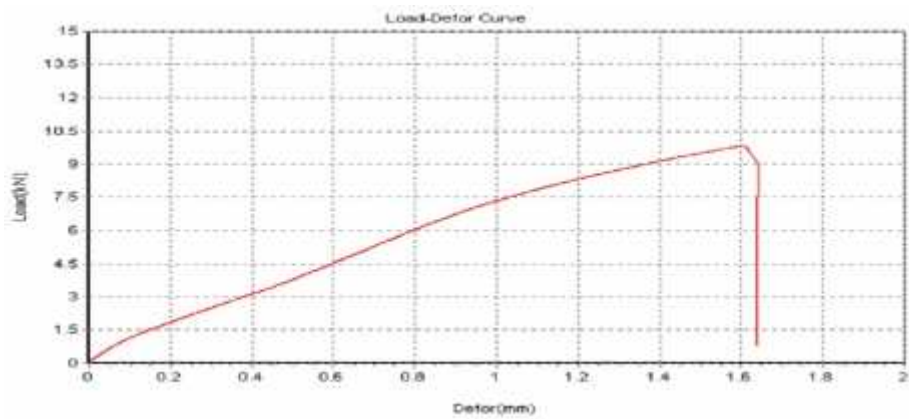
3.5. Tensile properties

The results of the tensile test and mechanical properties (tensile load, percentage of deformation and Ultimate tensile strength) of the prepared alloys are listed in Table (2) and Through figure (16, 17, 18). In the alloy A, a decrease in tensile value was observed (42 MPa). This is due to the presence of the zirconium component, which works to soften the crystals and form a phase (Al_3Zr) which is less stable as well, deposited on the crystalline boundary. . The alloy of B has a tensile value of (127 MPa). The reason for this is the presence of silver which acts as the formation of the phase ($AgAl_2Li$),(Al_2MgLi),($Al3Li$). In the solid-solution strengthening, the presence of copper with silver has precipitation strengthening zones that increase tensile strength and increase toughness. The C alloy found that the tensile strength decreased to (26 MPa) the reason for the presence of germanium, which works on the expansion but found when added to the aluminum alloy - Lithium increases the lithium's ability in aluminum, so it inhibits the phase deposition (Ge_4Zr_5) ,(Al_3Li) as long as in the rigid solution either After the process of aging, it is deposited in the form of rods that are almost identical, not cutable by the moving masses, thus reducing tensile strength.

Table 3 Tensile properties of the prepared alloys

No	Alloy	Tensile load (KN)	Deformation (mm)	Ultimate Tensile Strength (MPa)
5	A	3.20	25.0	42
6	B	9.82	24.3	127
8	C	1.55	45.0	26

Figure 16 Tensile Strength curve of A alloy

Figure 17 Tensile Strength curve of B alloy

Figure 18 Tensile Strength curve of C alloy

4.   Conclusions

1) Alloy is B superior then the A, C alloy In terms of mechanical properties.
2) The use of rolling and thermal coefficients and aging at 175°C temperature improves strength and hardness.

3) The addition of (0.35Ag %) of silver to the alloy increases the hardness and the strength by (70%) and reduces ductile.
4) The addition (0.2% Ge) of germanium to the alloy increases the ductile by a large percentage compared to the silver, and reduces strength to the hardness.
5) The appearance of many phases in the presence of silver such (AgAl$_2$Li),(Al$_2$MgLi),(Al$_3$Li is what made the increase in strength and hardness compared to other alloys.

5. References

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